

Studies on southern Australian abalone (genus *Haliotis*) XIV. Growth of *H. laevigata* on Eyre Peninsula

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ABSTRACT

The growth rate of *Haliotis laevigata* Donovan was examined at 6 sites on Eyre Peninsula, South Australia, by mark-recapture experiments and by analysis of length-frequency distributions. Juvenile growth rates were generally linear, and in the range 20 - 40 mm y⁻¹, whereas growth of older individuals was satisfactorily described by the von Bertalanffy growth curve. The Brody growth coefficient, K, ranged from 0.19 to 0.55 y⁻¹, and L_∞ from 119.5 mm to 186.3 mm according to site. Growth rates tend to decline with decreasing latitude.

INTRODUCTION

The management of exploited abalone resources requires an understanding of growth for the purpose of modelling individual stocks and fixing appropriate size limits. Because the growth rate of abalone is often variable between sites it is necessary to measure growth at a number of sites to determine the extent of variability.

The greenlip abalone *Haliotis laevigata* Donovan is heavily exploited on the west and south coast of Eyre Peninsula. The growth of the species in this part of its range has previously been known only from Waterloo Bay. The purpose of this study was to examine the growth of *H. laevigata* at a number of sites on Eyre Peninsula, as part of a program to review the management of the fishery at a finer scale. We analysed length - frequency data to measure juvenile growth (Shepherd 1988) and data from mark-recapture experiments for older individuals (Shepherd and Hearn 1983). These methods have been found to be the most satisfactory for this species of abalone.

MATERIALS AND METHODS

Six sites (Fig. 1) were selected to span the geographic range of the principal exploited stocks off Eyre Peninsula. The southern sites, Taylor Island and McLaren Point are on granitic substratum with numerous rounded boulders to 30 cm diameter at a depth of 5-10 m. The site at Ward Island is also on a granitic boulder substratum at about 10 m depth. The three northern sites are on an aeolianite substratum, eroded in part but with very few free slabs or boulders, at 5-7 m depth. All sites are more or less sheltered from the prevailing swell, but the two northernmost sites are the least, and the two southernmost sites the most, sheltered; Ward Island is intermediate.

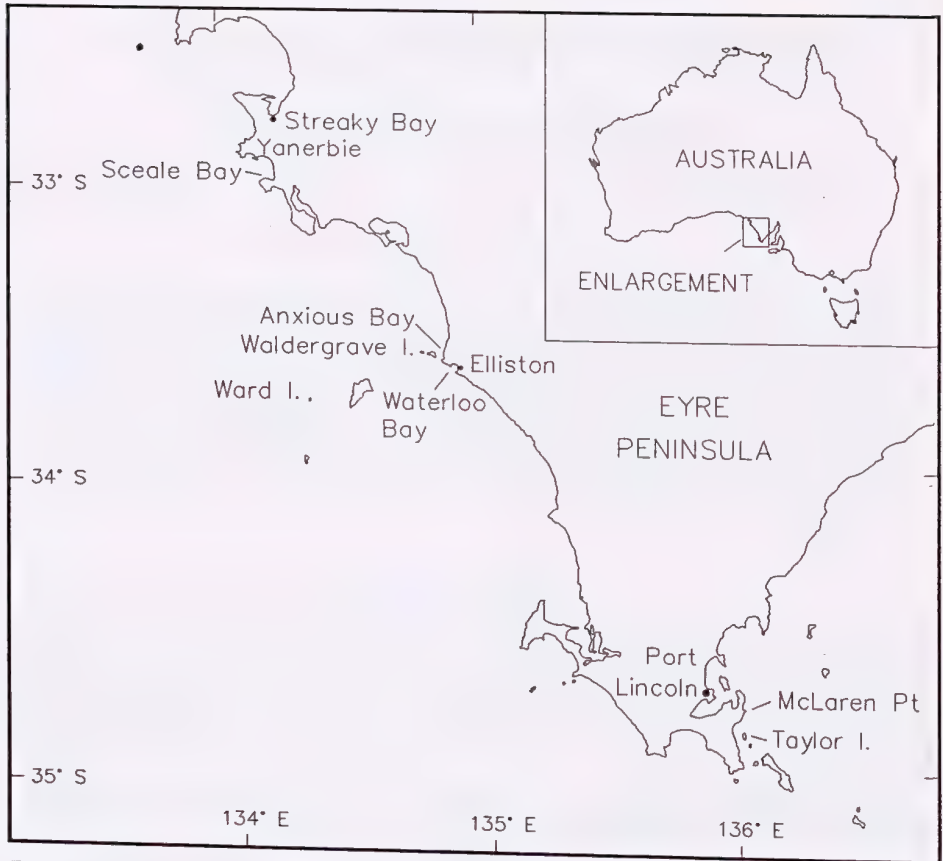


Figure 1. Map of Eyre Peninsula showing study sites.

Animals were marked by fixing a circular numbered plastic tag by a nylon rivet to the proximal pore-hole of the shell (Prince 1991). Marking was done in cool weather on the boat, or underwater, to minimise marking mortality. On subsequent visits to each site 9-18 months after marking, marked individuals were re-measured *in situ*. Unmarked populations of *H. laevigata* were also measured *in situ* to provide data for the preparation of length-frequency distributions. Except at Taylor I, where specific studies were made on cryptic juveniles, the smallest size classes (<50 mm shell length (SL)) were absent or poorly represented in the sampling.

Data Analysis

The von Bertalanffy growth equation has been widely used to describe the growth of abalone (Day and Fleming 1992). Estimates of the growth parameters, K and L_{∞} , and standard errors were obtained by fitting the von Bertalanffy equation, using the Fabens (1965) least squares algorithm (see Shepherd & Hearn 1983). To minimise possible seasonal effects we selected data for which the periods of freedom were not less than 270 days. Where multiple recaptures occurred, the final

recovery only was used, giving one data triplet (L_1 , t , L_2) per animal. T_0 was calculated from the youngest age-group to which the von Bertalanffy equation was fitted (Gulland 1985).

The MIX computer program was used to fit and separate modes of length frequency distributions. The procedure fits Gaussian curves and uses maximum likelihood methods to separate them (MacDonald and Green 1985). Probability values >0.05 indicate statistically satisfactory fits. The modes were allotted to an age class as described below and assumed a birth date on 1 December for all sites in accordance with concurrent studies on the reproductive cycle (see Shepherd *et al.* 1992).

RESULTS

Taylor I

A plot of the annual length increment data vs initial length from mark recapture experiments is given in Fig. 2. The mean annual growth rate of the putative 1+ age class (30-50 mm SL) was 43.4 mm (s.e. 2.2 mm) and that of the putative 2+ age class (65-99 mm SL) was 38.7 mm (s.e. 1.7 mm) which are not significantly different from each other (t test with pooled variance; $t_{32}=1.1$, $P > 0.1$). Hence the von Bertalanffy growth model, which requires a growth rate that declines by a constant amount as L approaches L_∞ , does not adequately describe the whole data set. For this reason we excluded the 5 data points of the putative 1+ age class and fitted the von Bertalanffy curve to the remaining data points (Table 1).

Table 1 Summary of growth parameters, T_0 , K and L_∞ , of the von Bertalanffy growth equation at different sites for *H. laevigata*. Sites are ranked from south to north, and data for Waterloo Bay (from Shepherd and Hearn 1983 and unpublished data) are included for comparison. Juvenile growth rates given in mm y^{-1} ; an asterisk indicates estimated rate. Standard errors in brackets.

Site	N	Juvenile Growth rate	T_0	$K \text{ y}^{-1}$ (s.e.)	L_∞ (mm) (s.e.)	r
Taylor I	41	20-43.4+	1.65	0.552 (0.087)	180.4 (10.3)	0.713
McLaren Point	35	23.6	1.65	0.368 (0.102)	178.3 (7.7)	0.534
Waterloo Bay	126	25	1.31	0.595 (0.036)	147.8 (1.8)	0.921
Ward I.	36	25.7	1.77	0.413 (0.053)	167.2 (5.2)	0.810
Anxious Bay	26	20*	1.11	0.385 (0.069)	119.5 (5.3)	0.744
Yanerbie	19	20*	0.94	0.268 (0.076)	140.4 (8.6)	0.642
Sceale Bay	9	23.6*	0.42	0.186 (0.042)	186.3 (28.2)	0.856

+ growth rate about 20 mm in first year and 43.4 mm in second year.

A length-frequency distribution from Taylor I (Shepherd *et al.* 1992) obtained in March 1988 with fitted modes is shown in Fig. 3. The modal means were then plotted against age (Fig. 4) assuming that the modes represent successive annual cohorts (Shepherd *et al.* 1992). The growth rate of the 1+ and 2+ age classes from the mark-recapture data (see above) are plotted for comparison (Fig. 4) and show good agreement with the growth rate inferred from the modes of the length-frequency distribution. We conclude that the first four modes represent annual age

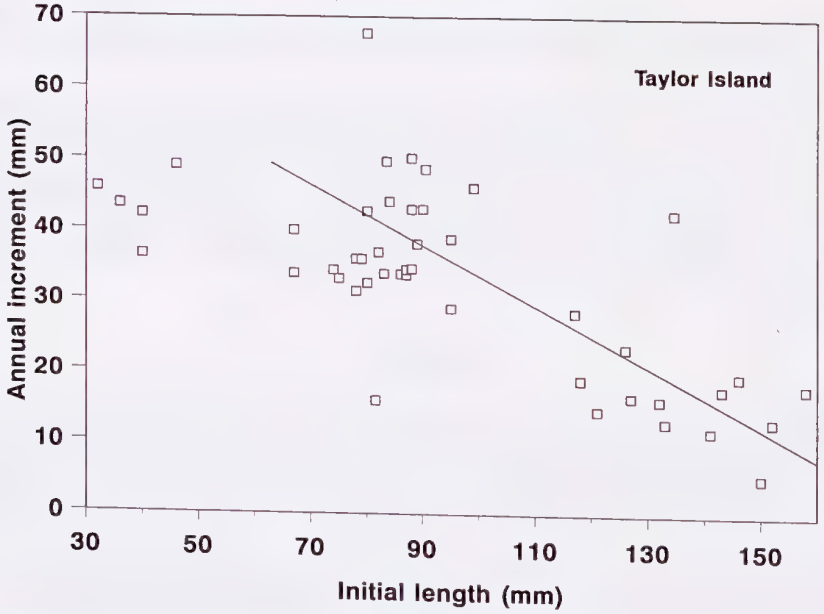


Figure 2. Plot of annual increment vs initial length for mark-recapture data from Taylor I. The fitted regression is shown.

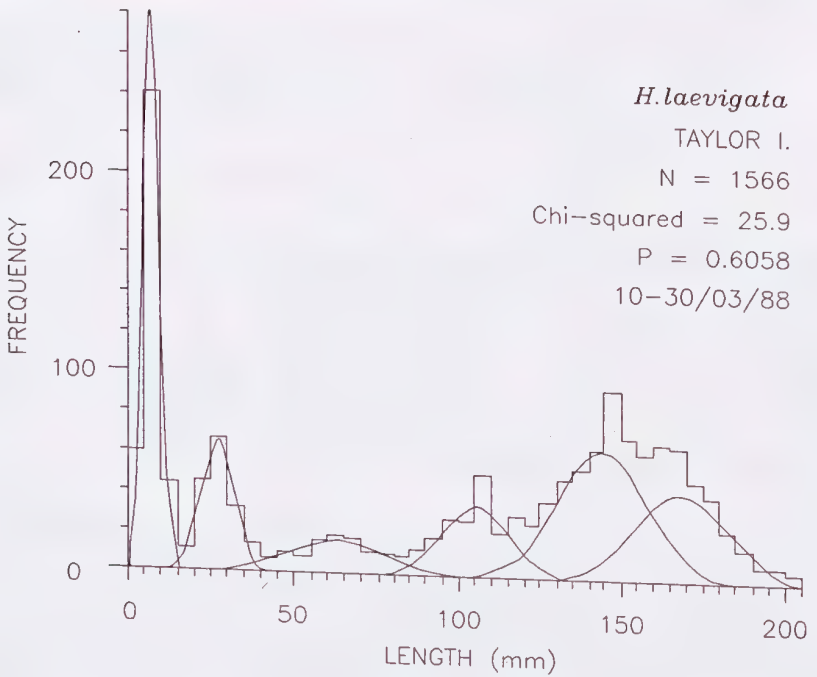


Figure 3. Length-frequency distribution, with fitted modes, for *H. laevigata* from Taylor I. Statistics of the fitted modes are given.

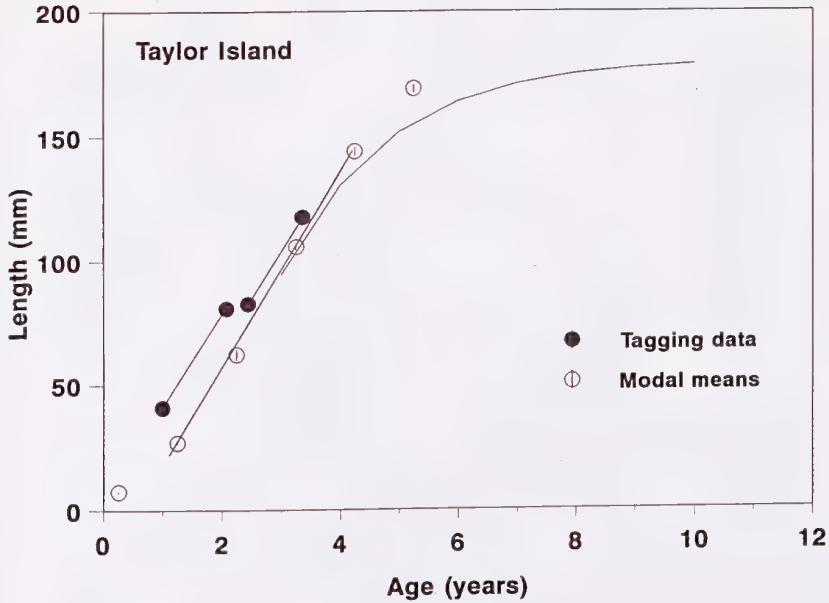


Figure 4. Plot of modal means (with standard errors) of length-frequency data (Fig. 3) against age. The fitted linear regression and plots of mean growth rate of 1+ and 2+ age groups of marked individuals are also shown. The von Bertalanffy growth curve for older age classes is shown by the curved line.

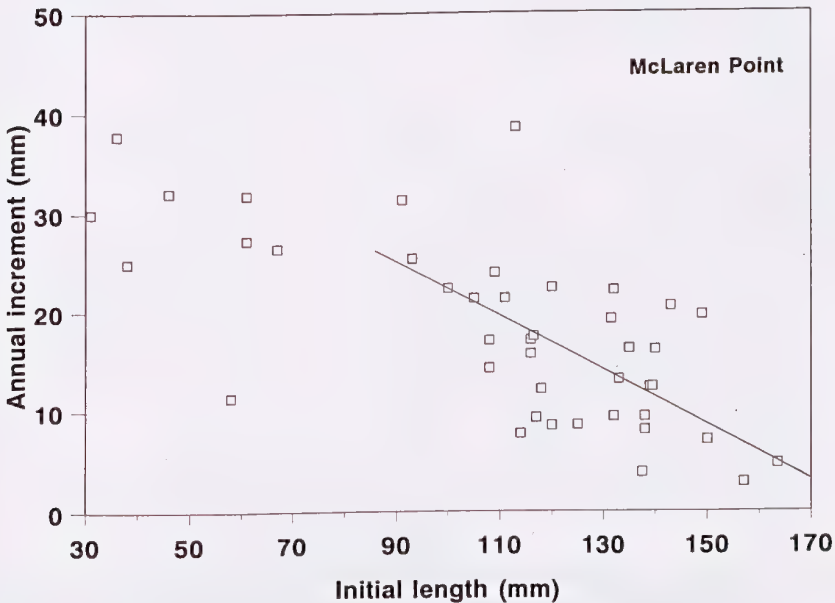


Figure 5. Plot of annual increment vs initial length for mark-recapture data from McLaren Point. The fitted regression is shown.

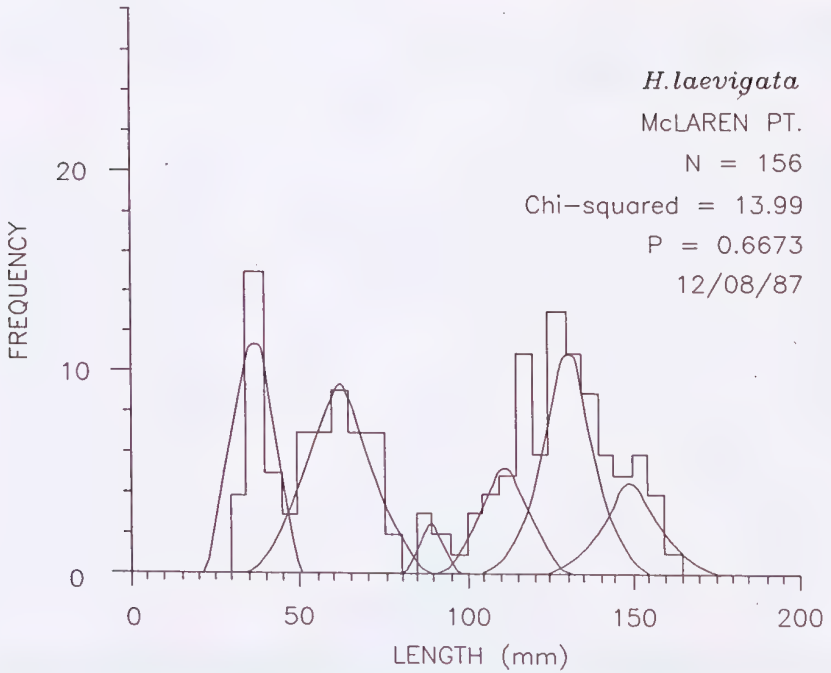


Figure 6. Length-frequency distribution, with fitted modes, for *H. laevigata* from McLaren Point. Statistics of the fitted modes are given.

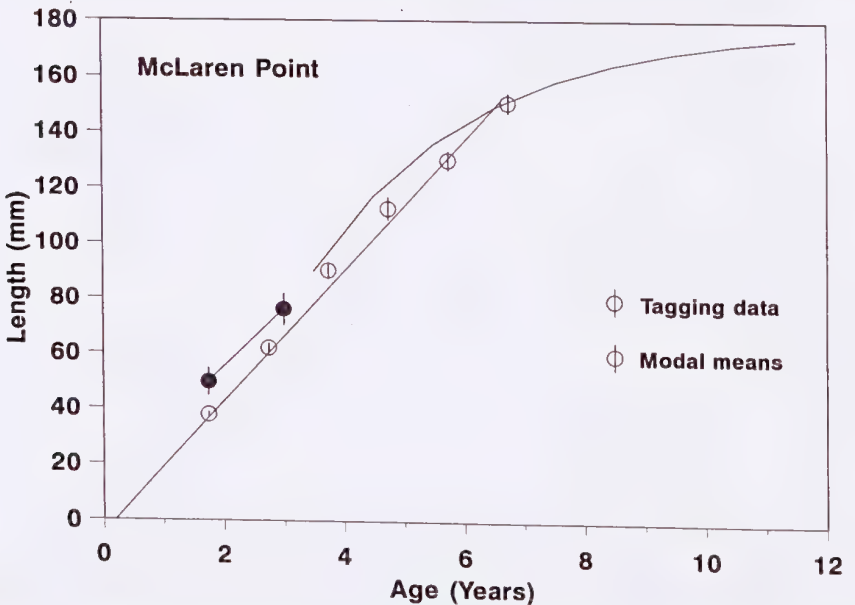


Figure 7. Plot of modal means (with standard errors) of length frequency data (Fig. 6) against age, with fitted linear regression for McLaren Point. Plot of mean growth rate of 1+ age class is shown. The von Bertalanffy growth curve for older age classes is shown and is displaced to the left slightly for clarity.

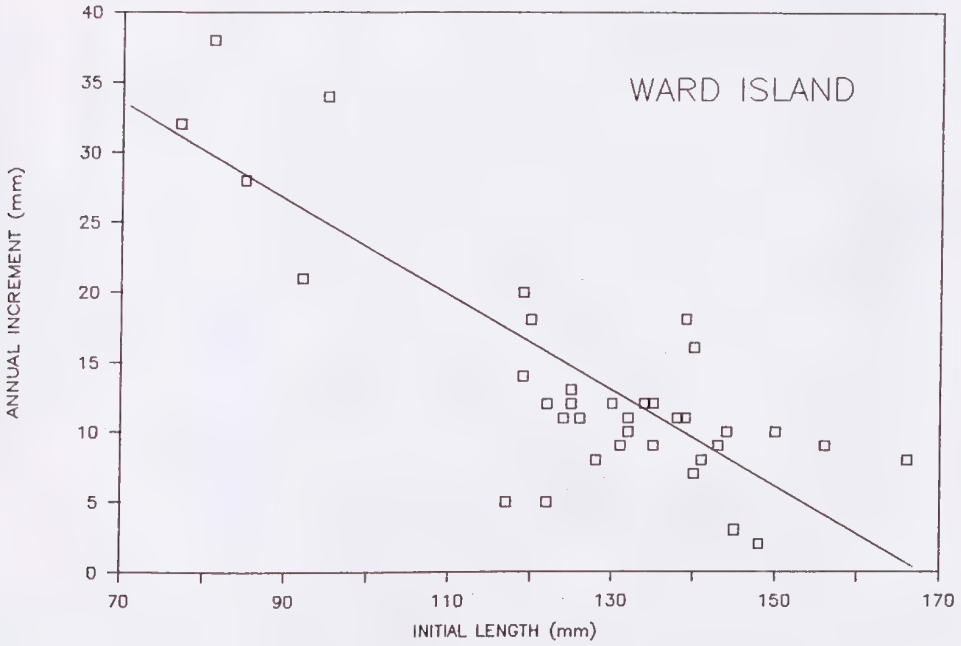


Figure 8. Plot of annual increment vs initial length for mark-recapture data from Ward I.

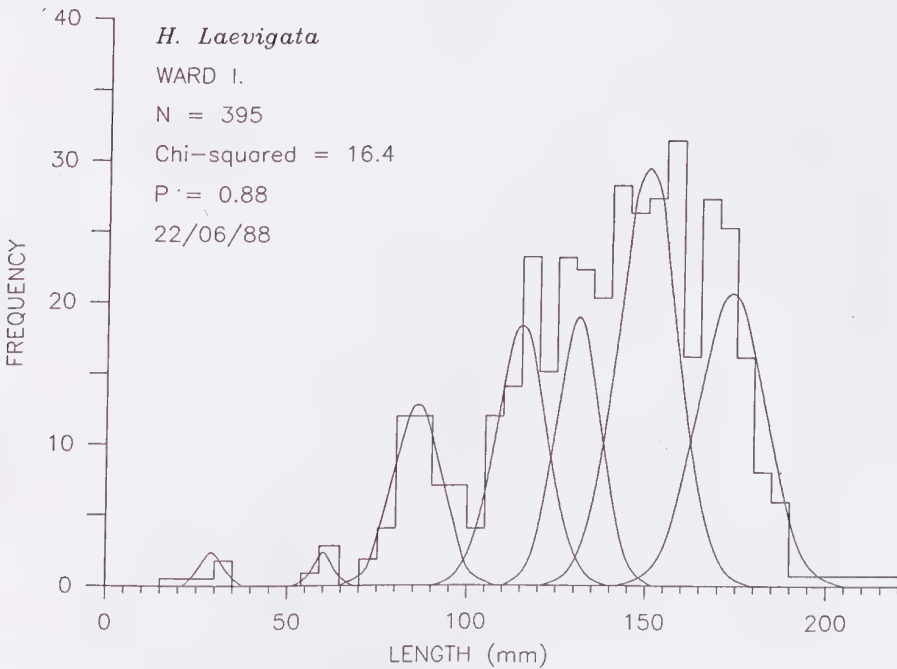


Figure 9. Length-frequency distribution, with fitted modes, for *H. laevigata* at Ward I. Statistics of the fitted modes are given.

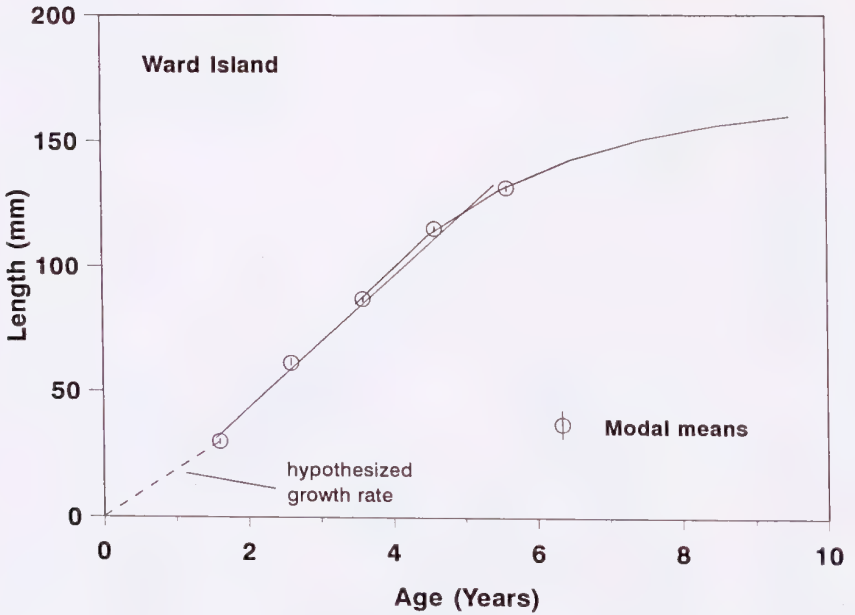


Figure 10. Plot of modal means (with standard errors) of length-frequency data (Fig. 9) against age with fitted linear regression, and the von Bertalanffy growth curve for older age classes from Ward I.

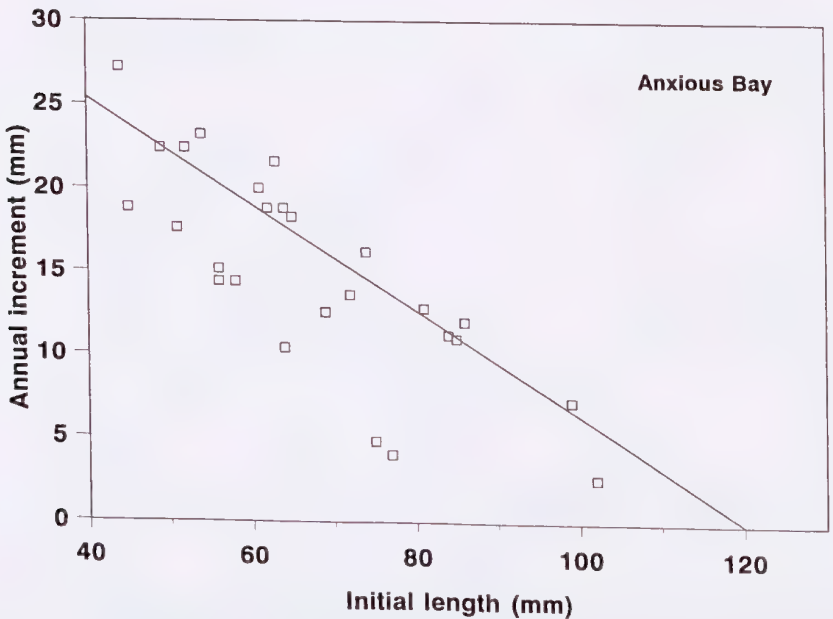


Figure 11. Plot of annual increment vs initial length for mark-recapture data from Anxious Bay. The fitted regression is shown.

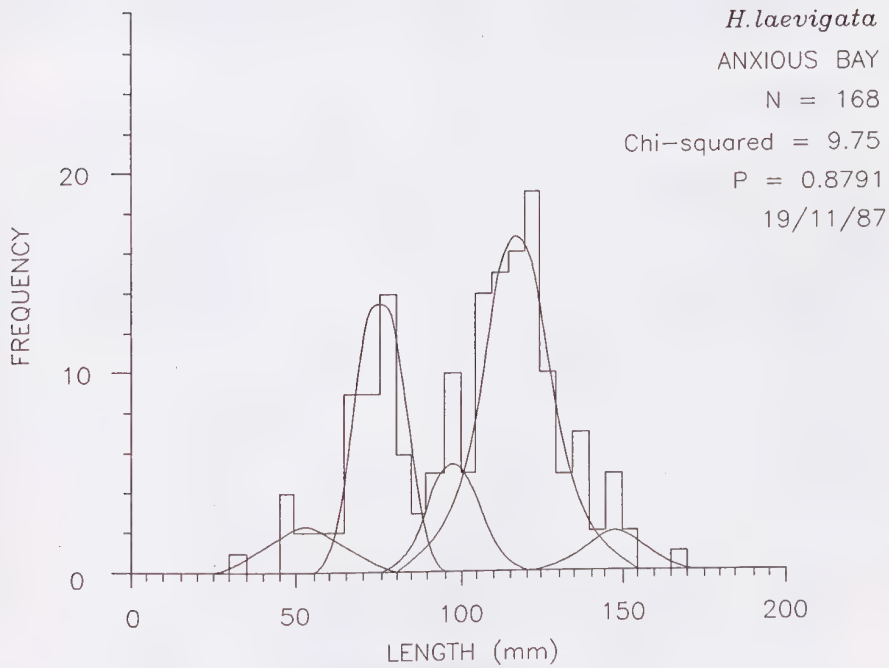
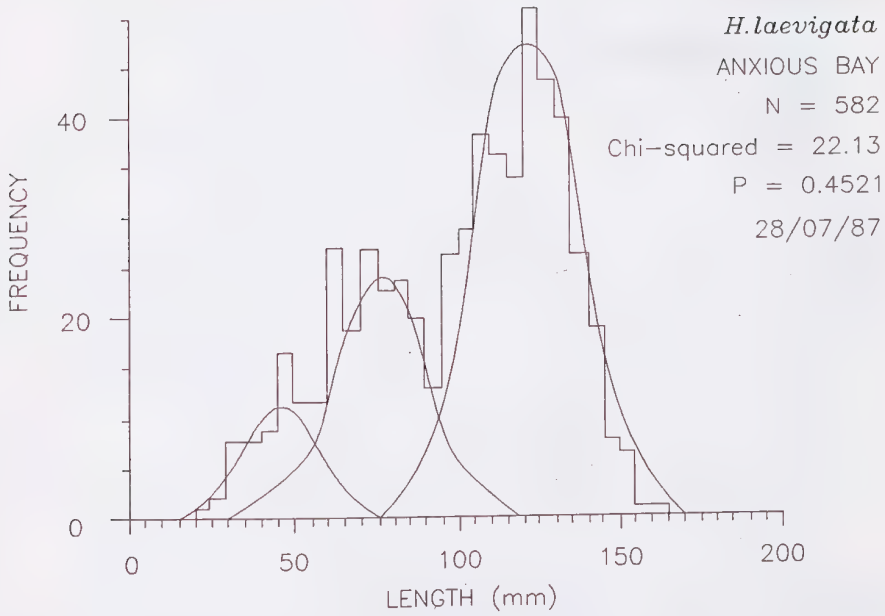


Figure 12. Length-frequency distributions with fitted modes from Anxious Bay. Statistics of the fitted modes are given.

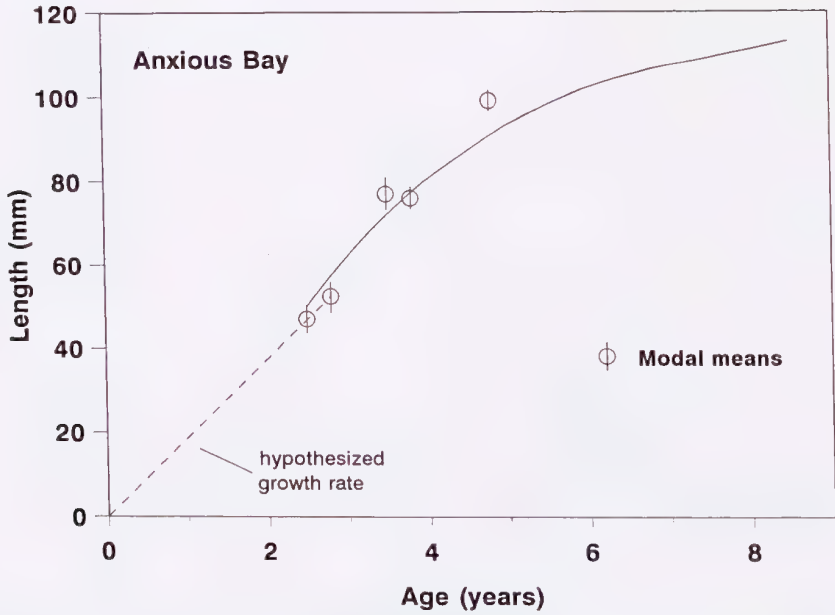


Figure 13. Plot of modal means with standards errors, of length-frequency distributions (Fig. 12) against age for Anxious Bay, with the fitted von Bertalanffy equation for mark-recapture data.

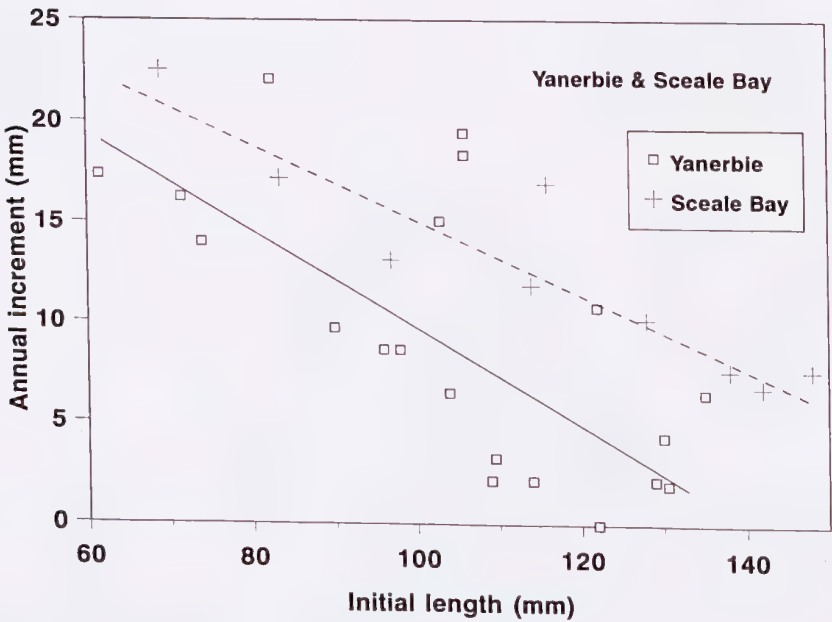


Figure 14. Plot of annual increment vs initial length for mark-recapture data from Yanerbie and Sceale Bay.

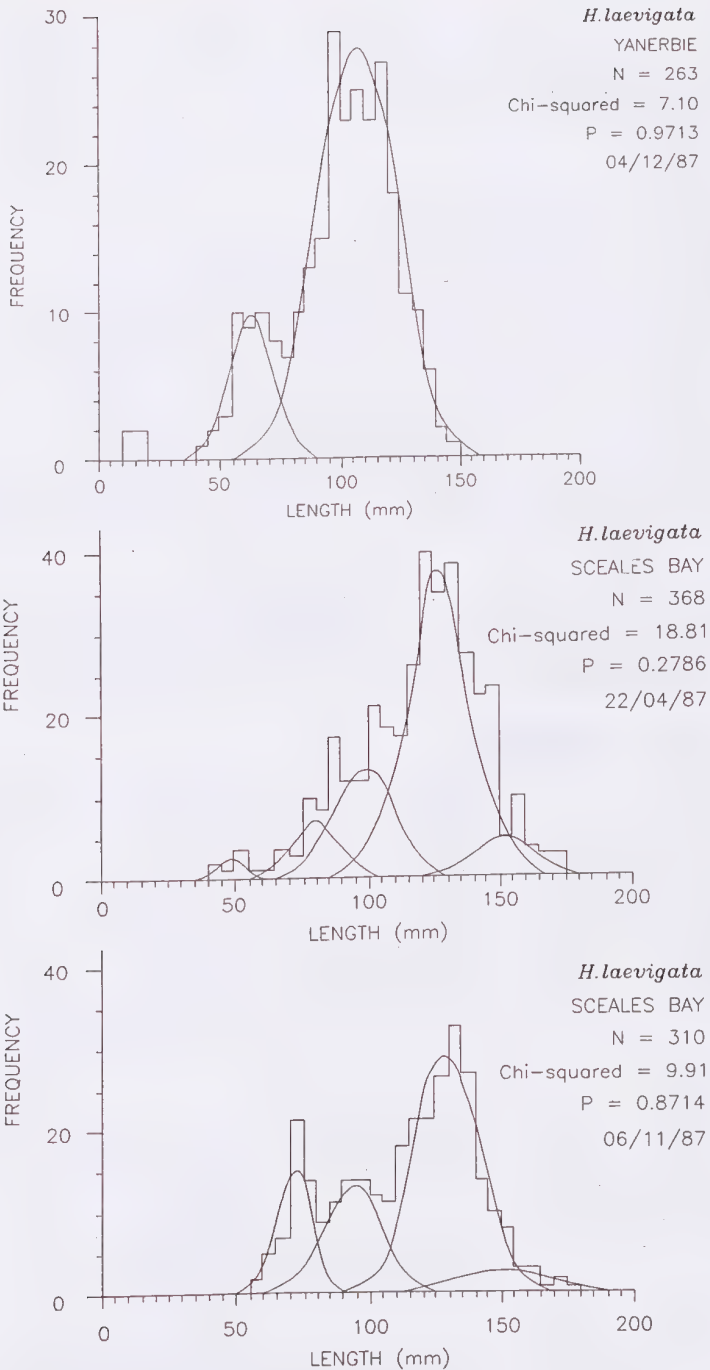


Figure 15. Length-frequency distributions with fitted modes, for *H. laevisgata* from Yanerbie and Scales Bay.

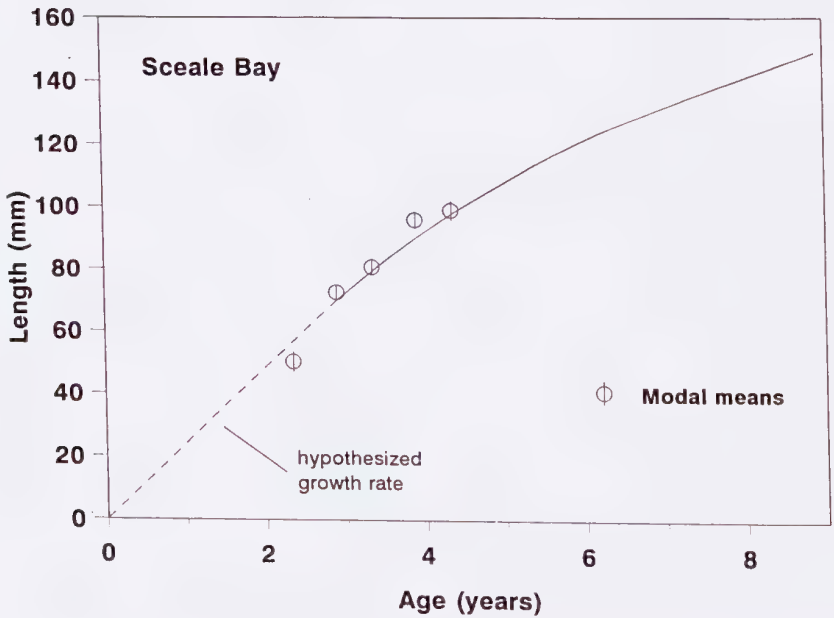
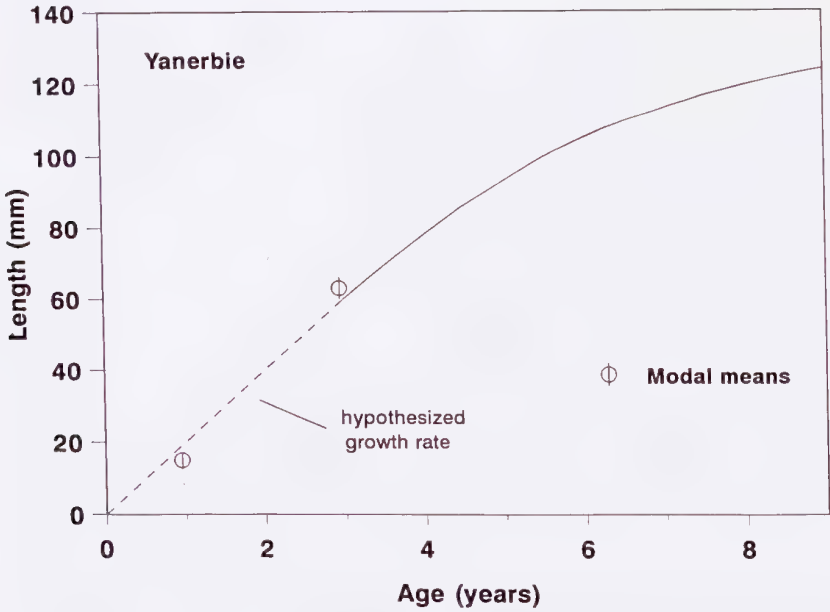


Figure 16. Plots of modal means, with standard errors, of length-frequency data (Fig. 15) against age and fitted von Bertalanffy growth curves for older age classes from Yanerbie and Sceale Bay.

classes; however the 5th and 6th modes are not well defined and probably include a mixture of age classes.

The 2nd to 5th modes inclusive are very nearly linear with age ($R^2 = 0.999$) and are described by the linear regression: $L = 39.6A - 24.1$ where L is the length in mm and A is the age in years.

McLaren Point

A plot of the annual increment data vs initial length (Fig. 5) and the apparent linear growth of juveniles (see below) suggested that, as for Taylor I., the von Bertalanffy equation might not adequately describe growth over the whole size range, so we excluded the putative 1+ and 2+ age classes (30 - 70 mm SL) and fitted the equation to the remaining data. Results are given in Table 1 and plotted in Fig. 7.

Length-frequency data taken at the site in August 1987, with fitted modes, are shown in Fig. 6. In contrast to Taylor I., searching could not be conducted in cryptic habitat, so the smallest (0+) age class is missing. The modal means were plotted against age, assuming the 1st mode was the 1+ age class. A linear regression was fitted to the modal means (Fig. 7) and gave the equation: $L = 23.6A - 0.53$ ($R^2 = 0.99$).

The mean growth rate from the modal data (23.6 mm y^{-1}) is consistent with the growth rate of marked individuals in the 1+ age class (26.3 mm y^{-1} ; s.e. 2.9 mm). We conclude that at least the first 3 modes represent annual age classes. The later modes are less certain and probably contain a mixture of age classes.

Ward I.

A plot of annual increment data vs initial length (Fig. 8) shows that the von Bertalanffy equation provides a reasonable fit to the data. The parameters of the fitted equation are given in Table 1.

Juveniles were rarely found, because cryptic habitat could not be sampled adequately. Hence the juvenile growth rate must be inferred from the modes of a length frequency distribution (Fig. 9). The 0+ age class is presumed to be missing, and those larger ones < 140 mm SL are probably annual cohorts. A linear regression fitted to the modal means gave the equation: $L = 25.7A - 7.6$ ($R^2 = 0.99$) ie. a juvenile growth rate of $25.7 \text{ mm year}^{-1}$. A plot of the growth curves for juveniles and adults is given in Fig. 10.

Anxious Bay

A plot of annual increment data vs initial length (Fig. 11) shows that a von Bertalanffy equation provides a satisfactory fit to all data. The parameters of the fitted equation are given in Table 1.

The population marked here appeared to be mobile. Small abalone predominated at the tagging site, but we observed a general movement of marked individuals off-shore into the direction of approaching swell.

Length-frequency data were obtained on two occasions. Cryptic habitat could not be sampled adequately, so it was not possible to determine the growth rate of juveniles. Modes were fitted to the length-frequency data (Fig. 12) and those modal means < 100 mm SL are plotted together with the fitted growth curve in Fig. 13. By assuming a mean length of 50 mm SL at age 2.5 years which is the juvenile growth

rate in similar habitats in neighbouring Waterloo Bay (unpublished data) the resultant growth curve agrees approximately with the position of the plotted modal means. The growth curve is tentative until more data are available.

Yanerbie and Sceale Bay

A plot of the annual increment data vs initial length (Fig. 14) indicates that the von Bertalanffy equation will provide a satisfactory fit to the data.

We analysed the growth data in the same way as for Anxious Bay. Juveniles were rarely found because we could not search cryptic habitat, so we could not characterise the juvenile growth rate. Only at Yanerbie were juveniles 10-20 mm SL found (putatively 1 year old) and these supported the postulated juvenile growth rate. Length frequency distributions and fitted modes are given in Fig. 15. Growth curves for the two sites derived from interpretation of modal means and from growth data are given in Fig. 16. Values for T_0 (Table 1) were calculated on the basis that the mean size of a 3-year-old is 60 mm SL at Yanerbie, and that of a 2.9-year-old is 70 mm at Sceale Bay.

DISCUSSION

An assumption of using tagging data to measure growth is that the tags do not affect the growth rate (Day and Fleming 1992). The rivet tag of Prince (1991) which we used has not been tested to determine whether it affects the growth rate. However we have observed that a layer of nacre is laid over the intrusive nylon part of the tag within 4-8 weeks, suggesting that interruption to growth (if any) is temporary.

The results show a weak trend of declining growth rate, as indicated by declining K values and slower linear juvenile growth rates, from south to north. Values for L_∞ are variable, but, as pointed out by Day and Fleming (1992), its value is dependent on the length range of the recapture data. In theory it is the maximum length to which individuals can attain, but, in practice, few large individuals are ever found in fished populations, so a lower value than the theoretical one usually results. In Anxious Bay the growth curve describes the growth predominantly of the inshore component of the population. This may explain the low L_∞ of 119.5 mm compared with the maximum observed size of 170 mm SL in the length-frequency data which included individuals further off-shore.

The growth rate of abalone has often been linked to the quality and availability of algal food; others have speculated that exposure to wave action plays a role (reviewed by Day and Fleming 1992). Our results agree qualitatively with the food supply hypothesis, although we have not attempted to quantify food availability. Algal drift is conspicuously abundant at Taylor I. and McLaren Point all year round, and often in banks up to 1 m high which inhibit searching. At Yanerbie algal drift is scarce and the site was selected because the abalone there are notoriously stunted. At the other sites algal drift is variable in abundance.

The growth rate data show no obvious relation with exposure to wave action. The two northernmost sites and Waterloo Bay have the highest exposure to wave action but with very different growth rates. The causes of the different growth rates observed can only be determined after a more detailed study of the habitat, which was beyond the purpose of this study.

ACKNOWLEDGEMENTS

We thank D. Graske, P. Clarkson, K. L. Branden, C. H. Deane and D. Lowe for diving assistance. Mr. G. W. Wright assisted with preparation of figures and A. Dalgetty with data analysis. Dr F. E. Wells and Paul Mulvay helpfully criticised the manuscript. The study was funded from the Fishing Industry Research Trust Account (Grant 86/61).

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